5236-101XZ

UNDERWATER IMAGING SYSTEM

BACKGROUND OF THE INVENTION

5   This application is a continuation-in-part of Application Serial No. 07/781,038, filed October 21, 1991, now abandoned.

This invention relates generally to an imaging system for detecting a target in a turbid
10   medium. More particularly, this invention relates to a system for detecting an underwater target using lidar.

Several techniques have evolved over the years for overcoming the problems associated with
15   detecting targets in a light scattering medium. One technique utilizes a narrow beam from a pulsed laser, such as a doubled YAG, to scan the ocean. Generally, the beam transmitter and the receiver aperture, which must be quite large to collect
20   sufficient energy, are scanned together, using scanning mirrors or other devices such as prisms. The energy received from each pulse is detected with a photomultiplier, or similar quantum-limited device, and the resulting signal is amplified with a
25   logarithmic response amplifier, digitized, and then processed. Because the pulses are short, typically 10 nanoseconds, the detection electronics must be very fast, digitizing at 200 MHz or faster. Since the pulse rate is low, the processing rates required
30   to analyze the data from each pulse are within the state of the art. Such methods require the use of mechanical scanners that are slow and difficult to build, particularly if they are to be mounted on aircraft. In accordance with a primary advantage of

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the present invention, the need for fast digitizing electronics and mechanical scanners is eliminated.

Another technique is range gating, which utilizes a pulsed flood beam and a number of gated image intensifiers with charge-coupled devices (CCD's). The intensifiers are gated on when the

5   beam pulse reaches a specific depth. Typically, the gate is applied just as the pulse beam that encounters the object returns to the receiver so that the full reflected return is obtained. A second intensifier is gated on a little later to

10   detect the shadow of the object. The image of the target is obtained by taking the difference of the two images which then eliminates the sea water backscatter and enhances the target signature.

There are numerous drawbacks associated

15   with the range gating technique. Specifically, range gating does not allow utilizing all, or substantially all, of the information returned from each pulse to create three-dimensional data sets. Rather, in such prior art systems, a volume of the

20   medium is illuminated and by range gating, a specific section of the illuminated medium is selected. Thus, the signal above and below the range gate is rejected. Consequently, of the energy transmitted into the volume of the medium, only a

25   small amount of the return is used. Additionally, a three-dimensional data set cannot be created from a single pulse. Rather, three-dimensional information can only be obtained by collecting many pulses, during which time the aircraft, or other vehicle

30   must remain stationary. A large multiplicity of shots is required to create an image, thus wasting energy from the laser.

Despite the availability of such

techniques, existing lidar systems are limited by
the size of the receiver optics that can be used in
a scanner. Generally, the light reflected from
targets which are deeply submerged or are submerged
in a very turbid medium is weak. Although large
aperture optics can aid in maximizing the amount of
light collected from weak returns, the size of the
optics that can be used in a scanner is restricted
by the size of the moving prisms or mirrors. Such
cumbersome mechanisms can be eliminated, as in the
present invention, by utilizing the motion of a
vehicle, a boat or an aircraft carrying the system
so that the dimensions for scanning can be reduced
to one. However, the scanning problem is still
formidable and restricts the size of the apertures
that can be used. Moreover, volume scanning systems
are very expensive, and require considerable power
and weight. Consequently, the ability to install
such systems in aircraft or other vehicles is
restricted.

Furthermore, those systems which utilize
range gating, instead of volume scanning, suffer
from poor range resolution and area coverage. When
the target is at a different depth than expected,
the target return will be subtracted as well as the
background, and poor performance results.
Additionally, very large pulse energies are required
to obtain sufficient signal-to-noise ratios to
detect objects at even moderate depths.

What is needed is an imaging system which
provides an accurate and reliable image of an
underwater target, eliminates the problems
associated with mirror scanning and utilizes all, or
substantially all, of the information returned from
each pulse to eliminate wasting energy from the

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laser.

The preceding and other shortcomings of
prior art systems are addressed and alleviated by
the present invention which provides a system which
5   can penetrate a turbid medium over a considerable
slice (width) without scanning or requiring fast
electronic devices.

SUMMARY OF THE INVENTION

10   The present invention provides an imaging
system for detecting a target in turbid medium, such
as water or air. The system includes a means for
generating a periodic series of discrete pulse beams
in the shape of fan beams, each of which are
15   substantially uniform in intensity, or with greater
amounts of energy at the ends of the fan to
compensate for losses due to the greater distance,
to illuminate sections of the medium.

In operation, a single pulse beam is
20   emitted to illuminate a section of the medium. A
large aperture optic collects the back reflected
portions of the pulse beam and focuses the reflected
portions on a field-limiting slit. The field-
limiting slit, located in front of the photocathode,
25   rejects multiply reflected light. A lens,
positioned between the field-limiting slit and the
photocathode, reimages the image on the field-
limiting slit onto the photocathode. Coupled to the
streak tube is an imaging detector, typically a CCD,
30   which detects signals generated by the streak tube
in response to the reflected portions of the pulse
beam impinging on the photocathode. Other imaging
detectors, such as a TV camera or photodiode array
may also be used   To obtain a volume display of the
35   medium, the generating means is moved normal to the

longitudinal axis of the pulse beam so that each
pulse illuminates adjacent sections of the turbid
medium. A volume display of the medium is thus
generated by combining the returns from adjacent

5   sections of the medium. All, or substantially all,
of the light returned from each pulse is utilized.

The photocathode on the streak tube is a
thin strip behind a field-limiting slit on which the
illuminated strip of the ocean, or scattering

10   medium, is imaged by the receiver optics. When the
laser beam pulse, typically a few nanoseconds in
duration, returns to the receiver from the surface
of the water, the electronic sweep of the tube is
initiated, so that the following time history of the

15   returning signal spread across the lateral surface
of the tube anode is then a record of the reflection
from the medium itself and from any submerged bodies
in the medium, such as mines or submarines,
including the reflection from the top surface of

20   such objects and of the shadow below them. Because
the slit cathode is long and covers the width of the
ocean illuminated by the fan-shaped beam from the
laser, the image on the anode phosphor or area
detector is a wide vertical section of the ocean.

25   In addition to imaging objects immersed and floating
in the medium, the invention also applies to imaging
objects on the bottom and to obtaining a profile of
bottom topography that may be the only way to
distinguish silt covered objects, such as

30   archaeological remains lying on the bottom, from the
bottom itself.

The invention described herein can be
employed, for example, from a fixed wing aircraft or
helicopter, from boats on the water surface, or from

35   submerged vehicles for search at great depths. The

invention is not exclusively restricted to use on oceans or lakes, but is useful in probing the contents of any turbid media through which light can pass, even if absorbed and scattered, as long as

5   some return can be obtained. For example, the invention can be used to detect a target in air. The items described in the following description are applicable to water probing, but there is no reason that the concept cannot be applied to the analysis

10   of smaller volumes using very short laser pulses, picoseconds duration for example, since the streak tube can capture such time intervals.

        The image on the anode can be photographed by means of a CCD camera or similar device,

15   particularly by logarithmic area array CCD-like detectors, which is read out slowly compared to the fast duration of the returning signal. The anode can also be replaced by a thinned backside illuminated CCD. This enables one to view the

20   phenomena on a cathode ray screen directly, or after encoding the signal, to enable one to process such images to obtain enhanced imagery through various means common to those versed in the art of enhancement, such as subtracting the mean return

25   from the recorded ocean section. The subsequent display of such ocean sections can be manipulated by adding many sections together to provide a three-dimensional view of the underwater scene. Such three-dimensional data sets, obtained by moving the

30   sensor system normal to the fan beam between each exposure so that each section is from an adjacent section of the ocean, provide the ability to enhance detection and reduce false alarms by rejecting images, such as fish, that might not be apparent in

35   any single section image. All of the light returned

is utilized in creating three-dimensional data sets, thus not wasting energy from the laser.

The foregoing and additional features and advantages of this invention will become further apparent from the detailed description and accompanying drawing figures that follow. In the figures and written description, numerals indicate the various features of the invention, like numerals referring to like features throughout for both the drawing figures and the written description.

BRIEF DESCRIPTION OF THE DRAWINGS

FIG. 1 shows a schematic showing of an aircraft employing the present invention to view objects underwater;

FIG. 2 is a block diagram of the preferred embodiment of the invention;

FIG. 3(a) - 3(c) is a timing diagram of signals obtained from use of the preferred embodiment in the system of FIG. 1;

FIG. 4 is a diagram of the beam distribution on the MCP, phosphor and CCD;

FIG. 5 is a schematic diagram of the laser and the projection optics of the preferred embodiment shown in FIG. 2; and

FIG. 6 is a schematic diagram of the detection system of the preferred embodiment shown in FIG. 2.

DETAILED DESCRIPTION OF THE PREFERRED EMBODIMENT

The present invention provides a system for detecting targets located in a light reflecting medium, such as water. The system can be utilized

5   to observe a water interface, the structure of the medium including the distribution of particulate matter or suspended bodies, a bottom profile, and objects included in any of these. More particularly, the invention can be used to detect

10   targets in any medium through which light can pass, even if absorbed and scattered, as long as some substantially directly reflected light can be obtained. For example, the system can be used to detect a target in air.

15   The system includes a light source for producing a series of discrete pulse beams which have a modified non-uniform intensity distribution to produce uniform signal-return. The reflected portions of the pulse beam are received by a

20   detection system comprising receiving optics, a streak tube and an imaging area detector. In operation, the invention is mounted on a vehicle adapted for movement over the target area. A light source emits periodic, narrow, fan-shaped pulse

25   beams to illuminate a succession of thin-slices of the turbid medium.

The detection system includes a light collecting optic, a field-limiting slit, a streak tube and an imaging area detector. The light

30   collecting optic collects reflected light and images it on a field-limiting slit, which rejects multiply scattered light. A lens, disposed between the field-limiting slit and a photocathode on a streak tube, focuses the image on the field-limiting slit

35   onto the photocathode. Because of the narrow fan-

shaped illumination and the field-limiting slit at the cathode, the light collected is substantially directly reflected light, and not light multiply reflected by the medium, thus providing improved image contrast.

To collect the maximum amount of light from weak returns, the aperture of the optic should be as large as possible. The photocathode on the streak tube, however, should be sufficiently large to encompass the image of the fan beam illuminated volume.

Inside the streak tube, the photoelectrons emitted from the photocathode are accelerated and then electrostatically focused on the phosphor layer or anode of the streak tube. On passage from the cathode to the anode, the photoelectrons pass through a deflecting electric field which causes the photoelectrons to sweep across the anode. The deflecting electric field is created when a varying voltage is applied to the deflecting plates in the tube. The result is a two-dimensional signal, consisting of the temporal variation of the detected light reflected from the turbid medium in one dimension, and the lateral position of the reflected light over the narrow, fan-shaped pulse beam in the other direction. The focused electrons can be sensed directly by an area detector, such as a thinned backslide illuminated CCD, or the electron energy can be converted to light by a phosphor. The light emitted from the phosphor layer on the anode is coupled to a detector array.

A volume display of the medium is generated by translating the transmitter and receiver normal to the longitudinal axis of the fan-shaped pulse beam to illuminate adjacent sections of

the medium, and combining the sections to provide a
volume display. All, or substantially all, of the
light returned from each pulse is utilized to create
three-dimensional data sets. The motion of the
vehicle is used to provide the scan or motion of the
fan-shaped pulse beam.

The present invention is not exclusively
restricted to analyzing the contents of large
volumes. By using very short pulses, picoseconds in
duration for example, the present invention can be
used to analyze smaller volumes. The streak tube
observes the rapid return of the backscattered light
by distributing the return in space and then reading
the return out slowly. The return is in nanoseconds
and picoseconds and the system of this invention
allows a readout in milliseconds, thus obviating the
necessity for faster electronic readouts. All of
the signal from each pulse of the fan-shaped pulse
beam width and depth that is back reflected is
observed at once, avoiding the need to use a
multiplicity of pulses to obtain three-dimensional
information.

Normally, laser beams are non-uniform in
intensity, with a maximum intensity at the center of
the beam and a minimum intensity at the outermost
edges of the pulse beam. This can be changed by
applying tapered coatings to the laser mirrors, or
by the use of optical means external to the laser.
An optical invertor, comprised of a series of lenses
and a diamond-shaped mirror arrangement, enhances
the intensity at the outer portions of the pulse
beam by optically inverting in one dimension along
the fan width the intensity pattern of the pulse
beam. The result is a pulse beam which compensates
for the effect caused by longer paths at the ends of

the fan to produce a signal return that is substantially uniform in intensity.

FIG. 1 shows a typical configuration of an aircraft 10, employing the present invention to detect underwater targets. The invention can also be used to detect targets in other turbid media, such as air. The invention can also be deployed from a vehicle such as a helicopter, a boat, or if searching at great depths, a submerged vehicle. A narrow, fan-shaped pulse beam 12 is projected from the transmitter to the water below, with the longitudinal axis of the pulse beam 12 normal to the direction of flight. The pulse beam 12 illuminates a thin section in the water. Coverage of a volume of the water is obtained by issuing a series of discrete pulse beams 16-18 to illuminate adjacent sections of the water. After processing the successive slice images, the sections can be displayed to show a scan through a volume of the medium. Thus, the motion of the vehicle carrying the system is used to provide the scan of the pulse beam. The pulse rate to generate the series of discrete pulse beams is set by the aircraft velocity. In general, the pulse rate may be high and the beam width on the water surface narrow compared to the resolution determined by the imagery detector pixels. This is done to preserve temporal resolution, which can be reduced if the spatial width becomes large. In order to reduce the number of readouts of the CCD, the pulses can be accumulated on chip.

FIG. 2 shows a block diagram of the preferred embodiment of the invention. A timing unit 20 initiates the probing sequence by causing a laser 22 to emit a narrow, fan-shaped pulse beam 12

to illuminate a thin section in the water. After
the Q-switch **84**, shown in FIG. **5**, in the laser **22**
has closed, causing the laser to fire, the timing
unit **20** initiates the variable delay unit **24**. The
5   variable delay unit **24** issues a delay pulse **26** to
initiate the receiving unit. In order to insure
that the delay is correct, a detector **28**, such as a
photomultiplier, is used to sense reflected portions
30 of the pulse beam. The timing unit **20** measures
10   this time and resets the variable delay unit **24** to
insure that the next delay pulse **26** is correct.
Since the delay is variable, the invention can be
operated at different aircraft altitudes.

         The reflected portions **30** of the pulse
15   beam are collected and focused on the photocathode
32 of a streak tube **34** by an optical element, shown
here as a lens **36**. The image, which includes a wide
spread of scattered light, is chopped by the field-
limiting slit **126** which is aligned with the image of
20   the fan-beam, and serves to reject scattered light
as well as limit the width of the electron image to
a width smaller than the temporal sampling obtained
by the pixels in the imaging detector. A lens **125**,
positioned between the field-limiting slit **126** and
25   the photocathode **32**, reimages the image on the
field-limiting slit **126** onto the photocathode **32**.
The photoelectrons **110** emitted from the photocathode
32 are accelerated by the streak tube anode voltage,
and are focused into a line on the anode **44** by the
30   electrostatic or magnetic field distribution in the
streak tube **34**, and are deflected by the
electrostatic field set up between the deflection
plates **40** and **42** in the streak tube **34**. In other
words, one field forms the image, and the other
35   field set up between the deflection plates **40** and **42**

moves the image.   The delay pulse **26** initiates the action of a sweep generator **38**, which causes a linearly increasing voltage **43** and **45** to be applied to the deflection plates **40** and **42** on the streak tube **34**.   The line electron image is deflected by the deflection plates **40** and **42** so that the line sweeps across the streak tube anode **44**, thus converting a temporal variation in the input signal into a spatial distribution on the anode **44**.   The anode **44** may be made of a phosphor, but since there are few photoelectrons **110** from the return when the beam has penetrated many diffusion lengths in the water, additional photon gain is desired.   Thus, the anode **44** is preferably made of a microchannel plate (MCP) intensifier, which provides the gain required to make photoelectrons **110** detectable.   The electron output of the MCP is converted to photons again by means of a phosphor layer **46**, so that the image of the temporal variation over the narrow fan-shaped pulse beam **12**, now converted to a two-dimensional image, can be coupled to a detector array **48** by a coupling device, such as a lens **50**.   Other coupling devices, such as a fiber optic, may be used.   The detector array **48** shown is a CCD, but it could easily be a diode array, and, in particular, a photodiode n-channel MOSFET array or diode limited CCD that provides a logarithmic response to high light levels.

If the accelerating voltage is high, gain can be obtained through the ionization created by the electrons directly in the detector.   Thus, the anode **44** can be made of a backside thin CCD fabricated for this purpose, and a MCP and phosphor are not required.

The CCD detector array **48** is set to

receive the image, before it arrives, by reading out
the preceding frame. Once the sweep generator has
completed the voltage rise and resets, a command is
issued to the video control **52** to read the image on
the CCD. The data is then passed to a processor **54**,
or directly to a cathode ray tube display **56**, where
a waterfall like display of the section of the ocean
probed by the pulse beam **12** can be seen. Typical
images are that of a water surface **58**, a reflecting
object **60**, and a shadow from the reflecting object
62.

The subsequent display of such ocean
sections can be manipulated by adding many sections
together to provide a volume display of the
underwater scene. Specifically, the sensor system
is moved normal to the longitudinal axis of the
pulse beam **12** between each exposure to illuminate
adjacent sections of the ocean. The adjacent
sections are then combined to obtain a volume
display.

As described, the present invention would
only be able to probe deep depths at night because
of solar illumination. For the system to operate in
the day, narrow band interference filters **124** are
required. The filters **124**, placed in front of the
photocathode **32** of the streak tube **34**, are designed
to pass the wavelength of the laser and block all
other wavelengths. The combination of the filters
124 and the short time each element in the detector
array **48** sees photoelectrons **110**, typically 5
nanoseconds thereby resolving 0.56 meter in depth,
would insure that no more than a few background
photoelectron count in any pixel would be obtained.

FIG. **3** shows a timing diagram of signals
obtained from the reflected portions **30** of the pulse

beam.   The time history of the reflected portions **30** of the pulse beam comprises a record of the reflection from the medium itself, and from any submerged bodies in the medium, such as mines or submarines, including the reflection from the top surface of such objects and of the shadow below them.   Because the part of the ocean illuminated by the pulse beam **12** is limited to a very thin section, the image on the phosphor layer **46** is a wide vertical section of the ocean.   The image can be photographed by means of a CCD camera or similar device, particularly by logarithmic area array CCD-like detectors, which read out slowly compared to the fast duration of the returning signal. Consequently, the phenomena on the cathode ray tube display **56** can be viewed directly, or the image can be processed by a processor **54** to obtain enhanced imagery after the signal has been encoded.   For the latter, various common enhancement means, such as subtracting the mean return from the recorded ocean section, can be utilized.

In the regions of the pulse beam in which there are no objects, as shown in FIG. **3(a)**, there will be a sharp return from the air-water interface **64** and then a smaller exponential return from the backscatter from the water itself **66**.   The signal will end with a second sharp return **68** from the bottom, assuming the system can reach such a depth. The range capability of the system will depend on the attenuation length of light in the medium traversed.   For example, the attenuation length of light in water varies from 40 meters, for Jerlov Type I clear ocean water, to a few meters, for Jerlov Type C turbid bay water.

When the pulse beam encounters a submerged

object, as shown in FIG. 3(b), the reflected
portions of the pulse beam will be typified by a
sharp leading edge 70 which will vary over the width
of the pulse beam due to the roundness of the
5   object. Following the return will be a shadow 72.
Thus, the combination of the sharp leading edge 70
and the shadow 72 will comprise the signature of a
submerged body.

In addition to detecting targets which are
10   immersed or floating in the medium, the present
invention also detects targets lying on the bottom
of the medium. When the beam encounters an object
on the bottom, as shown in FIG. 3(c), the system
will detect a return from an object on the bottom 74
15   before it will detect a return from the bottom where
no object is present 68. Thus, with a profile of
the bottom topography, silt covered objects, such as
archaeological remains or mines lying on the bottom,
can be distinguished from the bottom itself.

20   A diagram of the beam distribution on the
MCP, phosphor and CCD is shown in FIG. 4. The task
of detecting the various components out of the
return requires an analysis of the waveforms, such
as those shown in FIG. 3(a) - 3(c), over the width
25   of the fan. This analysis is enabled by the
principle embodiment of the invention that utilizes
the streak tube to present a spatial display of all
parts of the fan beam as a map of position versus
time, or depth.

30   The laser and the output projection optics
are depicted in detail in FIG. 5. The laser
required for the lidar of this invention is a
typical Q-switched laser that can produce pulse
widths of the order of 5 to 15 nanoseconds. For
35   purposes of illuminating the ocean and penetrating

it, wavelengths in the vicinity of 470 nanometers
are optimum.   In very turbid water, however, yellow
matter reduces the penetration at this wavelength so
that the optimum wavelength can be as long as 532
nanometers.   Applicable lasers are doubled Nd-YAG,
or Nd-YOS, Excimer lasers using the C- A transition
in XeF, and Copper vapor.   All of these can provide
considerable power, in the order of joules/pulse at
the reasonably high rates required for observations
from aircraft.   Diode pumped Nd-YAG for example
could provide 1 joule at 30 Hz.

Shown in FIG. **5** is a typical diode pumped
YAG laser, consisting of the YAG rod **74**, diode pumps
76 with a reflector **78**, and an output coupling
mirror **80** forming the resonant cavity of the laser.
The diode pumps **76** are driven by a diode driver **82**
triggered by the timing unit **20**.   When the rod **74**
has been exposed to the pump energy and is maximally
excited, the Q-switch **84** is opened and the lasing
action sweeps through the excited states to produce
an intense short pulse.   These lasers commonly emit
in the infrared, 1.06 micrometers.   However, a
nonlinear crystal in the path of the beam **86** can be
arranged so that the frequency of the radiation is
doubled to give the desired wavelength at 0.53
micrometers.

The output of the laser, for the energy
levels required, will be a beam with a half width of
4-6 mm.   The beam will be expanded so that it can
cover a 5 by 1500 meter area on the ocean surface
from a typical altitude of 1500 meters by means of
an anamorphic optical element which has a focal
length of -1.5 meters aligned with the flight
direction.   This would produce the 5-meter wide
slice and a focal length of -7.5 mm in the other

direction to produce the 1000 m cross track
illumination.

If the beam is gaussian **88**, an optical
invertor can be used to enhance the intensity of the
outer portions of the pulse beam. After the beam is
directed downward by a mirror **90** and slightly
diverged by lens **92** it arrives at a diamond-shaped
mirror arrangement **94** which cuts it into two parts
as shown by the dashed lines, and reflects it
outward to a set of mirrors **96**, which return the
beams to the central mirror arrangement **94**. Because
the beams reflect from three mirrors, the parts of
the beam that were outside **98**, and were the least
intense, now fall at the inside of the beam **100**. In
the same respect, the parts of the beam that were in
the inside **102**, which were the most intense, now
fall on the outside of the beam **104**. This results
in an inverted intensity pattern which then
compensates for the increased path length to the
ends of the pattern and for the cosine losses on
illumination and on the return, to provide a more
uniform signal over the illuminated region.

FIG. **6** is a schematic diagram of the
detection system with the preferred embodiment. The
most important part of the detection system is the
streak tube. Any of the existing and commercially
available designs are applicable to the invention,
but there are characteristics which make some streak
tubes better than others. The important
specifications are cathode size, resolution and
speed.

The photocathode **32** should be as wide as
possible to permit the use of a large light
collecting optic. This is because the signal E that
is collected by a detector element with an area A,

in an optical system with a numerical aperture n.a.
is given by the equation,

$$E = \pi \, B(n.a.)^2 A \qquad (1)$$

where B   =   magnetic flux density

n.a.= $1/(2 \not{x} \, f/\#)$,   f = focal length.

The brightness of the lidar return is given by the
laser energy, and the highly attenuated scattering
from the object, or the water. The numerical
aperture of the light collecting optics is limited
practically to 0.5, (f/1 optics), since the focal
length f is equal to the aperture diameter. The
only way to obtain an increased signal is to
increase the detected sample area on the
photocathode. For example, if a 30 mm long
photocathode (which could be as narrow as the field-
limiting slit) was used to cover 300 samples over
1500 meters of surface, the focal length of the
optic could only be as large as 17 mm, and the
aperture area to collect the return laser light
would only be 2.2 cm^2, which is very small. Large
photocathodes, however, are available in X-ray
imaging tubes and scintillation detectors, and
electron optics are capable of imaging the
photoelectrons. At present, there are intensifier
tubes with S-20 300 mm photocathodes which would
permit light collecting optics with aperture areas
as great as 220 cm^2 to be used. These intensifier
tubes have a signal strength 100 times greater than
the signal strength of smaller, more readily
available, tubes. Thus, the possibility of building
or obtaining a large streak tube which would utilize
the electron optics of larger intensifiers is well
within the state of the art.

In order to view a 1500-meter swath width,
the resolution of the streak tube should be

sufficient to permit observing 300 samples in width
and time. Moreover, to view depths of 150-300
meters, a streak tube should have 5-10 nanosecond
resolution.

5   Even with a photocathode **32** as large as
300x1 mm, as shown in FIG. **6**, the final image can be
placed on a CCD as small as 7.5x7.5 mm. (Standard
CCD size is 6.6x8.8 mm.) The light **30** from a fast
large aperture light collecting optic **36** (f/1, 170
10   mm focal length), shown in FIG. **2**, focuses on the
fiber optic input window **106** and passes to the
photocathode **32**. The extraction electrode grid **108**
accelerates the emitted photoelectrons **110** which are
focused on the phosphor layer **46** by the focus
15   electrodes **112**. A varying voltage **40** on the
deflection plates **40** and **42** causes the position of
the photoelectron beam **110** to change rapidly, giving
an output whose intensity versus distance is
proportional to the input intensity versus time.

20   At the phosphor layer **46**, the
photoelectrons **110** are converted to photons, with
some gain due to the accelerating voltage. The
photons are then coupled to a second photocathode
114 at the input of an image intensifier consisting
25   of microchannel plates (MCP's) **116**. This permits
the event to spread over the MCP structure to reduce
the poor noise factor caused by wide pulse shapes
and losses in pore structures that degrade typical
MCP performance. At the output of the MCP's **116**, a
30   second phosphor layer **118** converts the
photoelectrons to photons. The size of the second
phosphor layer **118** and the MCP's **116** is about 40 mm,
thus permitting a 30x30 mm image area. Typical
dynamic electron optic resolutions and MCP
35   resolutions are of the order of 10 lines/mm.

The last part of the detection system is
the coupling of the second phosphor layer **118** to the
detector array **122**. Coupling to the CCD is often
done by a lens **50**, as shown in FIG. **2**, or by a fiber

5   optic coupler. The demagnification required is
about the same in both cases, as is the loss in gain
of 16 that is the result of a 4x reduction to
typical 6.6x8.8-mm CCD's containing 25-micrometer
photodetectors.

10   Commercially available streak tubes have
photocathodes up to 30-mm in diameter, output
phosphors up to 44 mm in diameter, and may have
built-in MCP's. Speed and resolution are compatible
with the specifications given above.

While this invention has been described
with reference to its presently preferred
embodiment(s), its scope is not limited thereto.
Rather, such scope is only limited insofar as
defined by the following set of claims and all
equivalents thereof.